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The Prediction and Analysis of Water Resource Carrying Capacity in Chongqing Metropolitan, China.

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Abstract

The fast urbanization in Chongqing metropolitan has had a great impact on the environment and resources. The water resource has been recognized as one of the key elements to the sustainable development of this region. This paper presents a method of predicting the regional Water Resource Carrying Capacity (WRCC) using the supply-demand balance model. The method predicts that the WRCC of Chongqing metropolitan is from 8.8 million persons to 14 million persons in 2020 and it will not become the bottleneck of the social and economic development of Chongqing Metropolitan in the coming period of time. However the climate change and its impact on the regional ecology will have an effect on it. The results show that the usable capacity of Passing-by water is the most important element of the WRCC of Chongqing metropolitan therefore the protection of the ecological environment in the upstream area is very important. This paper has proposed tangible advice on the sustainable social and economic development in context of water resource

Keywords: sustainable development; water resource carrying capacity (WRCC); urbanization; Chongqing metropolitan.

1. Introduction

Sustainable utilization of water resources is vital to human existence and socio-economic sustainable development. With the rapid population growth and socio-economic development, the demand for water is increasing and water resources are under mounting pressure. Water resource has been recognized as one of the key elements to the sustainable development in a region, so study on the amount of available water resources is very important.

Water Resource Carrying Capacity (WRCC) has been recognized as a key indicator for study on the amount of regional available water resources. It still didn't get a united definition currently [1,2], but many foreign researchers, such as Rijsberman M.A.[3], Joardar S.D.[4]and Harris J.M.[5], already use the indicator to measure the amount of available water resources because of its importance. In China the

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earliest research of WRCC is in Xinjiang in 1985[6], later many scholars, such as Shi Y-F[7], Xv Y-P[8], Xv Z-M[9], Jiang X-H[10], Zhang Y-G[11], adopted various methods to calculate the WRCC in various areas.

According to analysis of above properties and research of Cao J-T[2] and Jiang W-C[12], a supply and demand balance model of regional water resources has been established in this paper. By using the model to make calculation of WRCC in Chongqing in 2020, the result of this study will provide reference data for various socio-economic medium-long term plans in Chongqing.

2. Methods and Study Area

2.1. Calculation Methods

The WRCC which limited by many elements, such as population, economy and environment, is a reflection of regional socio-economic development scale. It can be computed when the water resource is in a supply-demand balance.

The computational model can be defined as:

$$W_c = \max\ f\{c_1,\ c_2,\ c_3,\ \ldots, c_j\}\ . \tag{1}$$

$$W_{demand} = W_{sup\ ply}\ . \tag{2}$$

Where W_C is a regional WRCC, f is a comprehensive benefit function, C_j are various constraint indices, such as population, economic and environmental indicator. W_{demand} is the demand total amount of water resources for regional socio-economic development, $W_{sup\ ply}$ is the regional available total amount of water resources.

The demand total amount of water resources for regional socio-economic development (W_{demand}) includes domestic water consumption, productive water consumption and ecological water requirement. The productive water consumption mainly includes industrial water consumption and agricultural water consumption, the water consumption of tertiary industry is considered as a part of industrial water consumption.

The form of demand total amount of water resources (W_{demand}) can be presented as:

$$W_{demand} = W_D + W_I + W_A + W_E \tag{3}$$

Where W_D domestic water consumption, W_I is industrial water consumption, W_A is agricultural water consumption, W_E is ecological water requirement. The calculation forms of W_D, W_I and W_A can be presented as:

$$W_D = R_{DU} \times P_U + R_{DA} \times P_A\ . \tag{4}$$

$$W_I = U_I / P_I\ . \tag{5}$$

$$W_A = R_{AI} \times A_I\ . \tag{6}$$

Where R_{DU} and R_{DA} are urban domestic water consumption standard and rural domestic water consumption standard, its unit is L/（p•d）. P_U and P_A are urban population quantity and rural population quantity. U_I is the gross industrial output value, P_I is the average industrial output value of per unit water, and the unit of P_I is ten thousand Yuan/m^3. R_{AI} is the agricultural water consumption standard of effective irrigation area, its unit is m^3/hm^2. A_I is the agricultural effective irrigation area.

The ecological water requirement means the minimal water demand for supporting the integrality and the virtuous circle of ecological system in the region, which can be divided into the ecological water requirement inside river channels and the ecological water requirement outside river. The function of ecological water requirement inside river channels is mainly to prevent the dry river, to maintain the habitat of aquatic organisms, to keep riverbed stability and water self-purification ability. The ecological water requirement inside river channels account for 50~60% of annual average runoff volume in general[13]. The ecological water requirement outside river mainly includes ecological water requirement of vegetation, lake and wetland etc, which is relatively constant and depends mainly on regional ecological environment status and ecosystem type. In urban area, the ecological water requirement outside river also includes urban municipal water consumption[14].

The calculation forms of regional socio-economic development scale can be defined as :

$$U = U_I + U_A = U_I + P_{RA} \times A_R . \tag{7}$$

$$U_P = U / P = (U_I + U_A) / P = (U_I + P_{RA} \times A_R) / P . \tag{8}$$

$$P = P_U + P_A = P \times r + P \times (1 - r) . \tag{9}$$

Where U is industrial and agricultural gross output value, U_P is per-capita industrial and agricultural output value. For making the equations be easy to calculate, GDP and per-capita GDP can be instead of U and U_p. U_A is agricultural gross output value, P_{RA} is unit area agricultural average output value, A_R is area of agricultural production, P is population quantity, and r is urbanization rate.

The regional available total amount of water resources ($W_{sup\,ply}$) includes regional internal total water resources quantity and regional external water flow. The regional internal total water resources quantity includes surface and subsurface water yield from local precipitation, the surface and subsurface water yield is called too surface water resources amount and ground water resources amount.

The regional external water flow means available input amount of water resources from external region.

The calculation forms of regional available total amount of water resources ($W_{sup\,ply}$) can be defined as :

$$W_{sup\,ply} = W_R + W_{Ex} . \tag{10}$$

Where W_R is regional internal total water resources quantity, W_{Ex} is regional external water flow.

On condition that dimension is neglected, with solving simultaneous equations (2)~(10), the WRCC can be calculated and be defined as:

$$P = \frac{W_R + W_{Ex} - W_E + P_{RA}A_R/P_I - R_{AI}A_I}{R_{DU} \times r + R_{DA} \times (1 - r) + U_P/P_I} . \tag{11}$$

Where P is the regional Water Resource Carrying Capacity (WRCC). If the regional available total amount of water resources ($W_{sup\,ply}$), urbanization rate and other related technical and economic indicator can be predicted in a region, the regional population size (WRCC) can be calculated.

2.2. Study Area

located at the Confluence region of Chang River and Jialing River and in the Southwest of Chongqing municipality, Chongqing metropolitan consists of Yuzhong district, Jiangbei district, Shapingba district, Jiulongpo district, Nan'an district, Banan district, Beibei district and Yubei district. Covering an area of 5479.3 square kilometers, there is commercial and industrial center of Chongqing municipality [15].

Chongqing metropolitan's GDP is 1793.37 hundred million Yuan in 2007, in which the primary industry is 95.95 hundred million Yuan (5.35%), the secondary industry is 807.73 hundred million Yuan (45.04%) and the tertiary industry is 907.62 hundred million Yuan (50.61%). Chongqing's per capita GDP is 26956 Yuan and its total resident population is 5.91 million in 2007, there is a high speed of urbanization in Chongqing metropolitan, of which annual average growing rate of urban population is 2% from 1998 to 2007 [15].

3. Results and Discussion

According to the conditions of Chongqing metropolitan's middle-to-long term social economic development planning compilation and the time effectiveness of WRCC, the calculation time of WRCC was determined as 2020 in this paper.

4. Demand Total Amount of Water Resources (W_{demand})

4.1. Domestic water consumption

The domestic water consumption includes urban domestic water consumption and rural domestic water consumption.

The urban domestic water consumption mainly includes resident living water, resident municipal water, environmental sanitation and Greening water, in which the resident living water occupy 50%~70% in general. The rural domestic water consumption mainly includes resident living water, environmental sanitation and drinking water of livestock. The urban and rural per capita domestic water consumption is respectively 212 L/d and 68 L/d in China at present[13], Chongqing metropolitan's per capita domestic water consumption is about 112 L/d and 68 L/d at present[16].

According to the regulations Ministry of Housing and Urban-Rural Development of the People's Republic of China and Ministry of Health of the People's Republic of China, the urban per capita resident living water consumption standard is 100~140 L/d in Chongqing, the rural per capita resident living water consumption standard is 50~90 L/d in Chongqing[17].

Considering the Chongqing metropolitan's social economic will reach a higher level in 2020, the urban per capita domestic water consumption standard was determined as 212 L/d, and the rural per capita domestic water consumption standard was determined as 105 L/d in this paper.

4.2. Productive water consumption

The average industrial output value of per unit water was about 50 Yuan/m^3, and the agricultural water consumption standard of effective irrigation area was 30 m^3/hm^2 in recent years in China[13]. The

average industrial output value of per unit water and the agricultural water consumption has an increasing trend in Chongqing in recent years[15]. In Chongqing, the ten thousand Yuan industrial water consumption is 135 m^3, and the agricultural water consumption of per unit area is about 3255 m^3/hm^2 in 2006[16].

According to analysis of above indicator and research of Wang H[13], the Chongqing metropolitan's ten thousand Yuan industrial output value standard was determined as 40 m^3, and the Chongqing metropolitan's annual agricultural water consumption standard was determined as 6675 m^3/hm^2 in 2020 in this paper.

According to the scheme of The Chongqing's Eleventh Five-Year Plan for National Economic and Social Development, Chongqing's per capita GDP was determined as 45000 Yuan in 2020 in this paper.

The agricultural output value accounts for GDP proportion is 3.16% in 2007 and has a decreasing trend in recent years in Chongqing metropolitan [15]. The agricultural output value accounts for GDP proportion was determined as 2% in 2020 in this paper, and the agricultural gross output value was determined as 8000 million Yuan, agricultural average output value per hectare was determined as 15 ten thousand Yuan, the agricultural effective irrigation area was determined as 4 ten thousand hectares.

According to The Urban-Rural Master Planning of Chongqing (2007-2020), Chongqing metropolitan's urbanization rate was determined as 85% in 2020 in this paper.

4.3. Ecological water requirement

According to analysis of above paragraphs，the ecological water requirement inside river channels was determined as 60% of annual average runoff volume in this paper.

Landform of Chongqing metropolitan is Paralleled Ridge-Valley of East Sichuan, and there is higher vegetation coverage in Chongqing metropolitan. Combining with research of Lin C[18], the ecological water requirement outside river of Chongqing metropolitan was Predicted as 15% of total amount of regional water resources in 2020 in this paper

5. Available Total Amount of Water Resources ($W_{\sup ply}$)

5.1. Total amount of water resources.

In general, total amount of regional water resources is the average value for many years. According to analysis of Chongqing Municipal Bureau of Water Resources，the total amount of regional water resources is 29.8 billion m^3, and thel annual average runoff volume is also 29.88 billion m^3 in Chongqing metropolitan [16].

5.2. Regional external water flow

he regional external water flow includes artificial water diversion and available amount of transit water. There isn't relevant planning of artificial water diversion from external region in Chongqing metropolitan, so the regional external water flow of Chongqing metropolitan is mainly available amount of transit water of Chang River and Jialing River.

According to the research of Luo J-Y[19], The transit water amount of Chang River and Jialing River is enormous in Chongqing metropolitan, its average value for many years is 3379.7 billion m^3.

The available transit water mainly depends on the reasonable distribution of transit water in its basin. The water distribution method of river basin isn't generally accepted at home and abroad in recent, but regional fairness principle is fundamental for reasonable distribution of transit water in its basin[21]. In a

sense, the regional fairness principle needs to reflect difference between upstream and downstream of a river basin in land resources and social economic development level and needs to keep sustainable development of whole basin. So the land area proportion and population quantity reflecting social economic development level are considered to be basis for distribution of transit water in its basin in this paper.

Chongqing metropolitan's land area accounts for 6.6% of total area of Chongqing municipality or accounts for 0.3% of total area of Chang River basin, and its population accounts about for 18.25% of total population of Chongqing municipality or accounts about for 1.46% of total population of Chang River basin [15]. By comprehensive consideration of Chongqing metropolitan's land area and the socioeconomic status of Chongqing metropolitan in Chang River basin, the 0.88% and 1.46% are considered to be lower limit value and upper limit value of available transit water amount proportion of Chongqing metropolitan in this paper. Hereby, available transit water amount of Chongqing can be calculated, its value is 29.7414~49.3436 billion $m^{3.}$

According to equations (10), the available total amount of water resources can be calculated, its value is 58.845~79.154billion $m^{3.}$

6. Water Resource Carrying Capacity(WRCC)

According to equations (11) and determined data in above paragraphs, the WRCC can be calculated in Chongqing metropolitan, its value is 8.8~14 million people in 2020. Chongqing metropolitan's population is 5.91 million in 2007[15], so water resource will not become a main limiting element of Chongqing metropolitan's social economic development in a short coming time.

7. Conclusions

WRCC is a key element for sustainable utilization of regional water resources. According to the calculation results of this paper, for reducing the effects of water resource to Chongqing metropolitan's social economic sustainable development, the Chongqing municipality government in more detail enhances the following several respect：

1.To establish the water distribution agreement of relative river basin of Chongqing for ensuring calculation accuracy of WRCC. It's a difficulty to calculate the available transit water amount in WRCC, the reasonable distribution of transit water is a key element for calculating available transit water amount.

2.To ensure realization of various technical and economic indexes. Various technical and economic indicators are constraint conditions to calculate regional WRCC. The calculation of WRCC isn't only to calculate the regional population scale, the calculation and realization of various technical and economic indicators are important too. Calculation result of WRCC may be a bigger error if some technical and economic indicators cannot achieve.

3.To establish water-saving society for improving the Chongqing metropolitan's WRCC. According to the supply and demand balance model of regional water resources in this paper, when the regional available total amount of water resources keeps invariant, reducing the demand total amount of water resources can improve the regional WRCC. It's very important for improving water use efficiency, reducing water pollution, ensuring ecological water use and realizing regional sustainable development to establish water-saving society.

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